TERRESTRIAL PHOTOGRAMMETRY WITH A 360° CAMERA

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TERRESTRIAL PHOTOGRAMMETRY WITH A 360° CAMERA

A thesis presented to the faculty of Rensselaer Polytechnic Institute in partial fulfillment of the requirements for the degree of Master of Civil Engineering.

by

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and

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ABSTRACT

Terrestrial photogrammetry with a camera taking a continuous picture for 360° around a point and the method of plotting from the resultant positives by the use of transparent overlays was studied. Conclusions reached were that the method used definitely shortens the process of obtaining topographic maps from photographs and reduces the calculations and work necessary to produce a map of sufficient accuracy to be of practical value.

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INTRODUCTION

INTRODUCTION

The science of photogrammetry, while not a new or untried method of map construction, is nevertheless one of the lesser known fields in the broad expanse of subjects covered by Civil Engineering. This undoubtedly stems partially from the fact that maps made by this method require not only the usual field and office equipment necessary for the general run of topographic work, but in addition, expensive cameras, and a host of related equipment. All of which usually brings the cost of producing the map to such a prohibitive figure that only the largest concerns can afford to own this equipment and take advantage of the saving in time that photogrammetry provides.

Terrestrial photogrammetry tends to limit itself to a more specialized field than does aerial photogrammetry simply because some areas are definitely not suited to photography from the ground. Heavily wooded areas, or mountainous terrain with rapid changes in elevation, for instance, would be difficult to photograph because of light conditions, or inability of the camera to "see" far enough to make the resulting photograph of practical use. In areas with mountains and valleys it may be impossible to so locate the camera that all of the area required will be within the field of view.

There are cases on record, however, where terrestrial photogrammetry was employed with a great deal of success in rugged terrain where ordinary surveying methods would have been limited because of short availability of good weather in which to work. In the years 1911-14, a topographic survey was made of various regions of Alaska, by the U. S. Geological Survey, including the Port Valdez and Broad Pass areas using the methods of terrestrial photogrammetry covering approximately 12,201 square miles and saving an estimated one quarter to one third the cost of the usual plane table methods.

At the present time, the method usually employed in taking pictures for terrestrial work is to use a large film or plate camera mounted on a tripod or other steady support and take pictures about the point occupied until enough have been obtained to cover the desired area. Some method must be provided to rotate the camera about the vertical axis in order that the tripod remain undisturbed and the height of instrument remain constant for the series of pictures taken about the point. This system has the obvious disadvantages of carrying several plate or film packs into the field, the possibility of not taking sufficient pictures around a point and thus excluding important data that might not be noticed until later in the office, and the necessity for having an accurate view finder which again might result in leaving out important data. In addition, it might be said that at best, only the

central portion of the photograph should be used where accurate measurements are desired due to the inherent distortion acquired in taking a three dimensional view and transfering it to a large, flat plate, plus the distortion in the lens.

After the pictures are taken, developed and printed, it becomes necessary to proceed through a rather long and complicated procedure before the objects in the pictures are transfered to the map. Essentially this consists of orienting the pictures or picture traces with reference to the point occupied; picking some common object on at least two pictures taken from different points; determining the distance from the principal line of the picture to the image of the object on the two pictures; setting off these distances on the picture traces; connecting, on the map, the points occupied and the image distances previously set off on the picture traces to produce two intersecting lines that will locate the object in question. It may easily be seen that this may become a rather laborious process, especially when the area covered is somewhat large and a large number of pictures are used.

The authors, in conjunction with Mr. J. H. Kunzer of the Civil Engineering Department, Rensselaer Polytechnic Institute, have devised a type of camera and method of applying the resultant picture which they believe will eliminate several of the steps listed above as well as some of the inherent disadvantages of the film pack or plate camera

previously discussed. Briefly, the camera consists of a revolving element carrying a film magazine and lens system, and the film magazine carrying a long strip of film which, when properly exposed, results in a picture that is continuous and complete showing all the objects visible to the camera for a complete revolution about the point occupied. The picture from the camera is about three and one half feet long and six inches wide, providing a picture large enough to get accurate detail without enlargement. The immediate advantage of this camera is seen to be the ability to include everything within range on one exposure and one setup. The fact that the camera may be loaded for more than one exposure precludes the necessity of carrying extra plates or film packs into the field, thus making one less item to handle. The design of the unit utilizes only the central portion of the lens in a horizontal direction, hence the entire picture is useful for plotting data with the possible exception of the extreme upper and lower portions. These portions of the picture are of little consequence in the usual terrain encountered in terrestrial photogrammetry since they consist of sky on one hand and objects extremely close to the camera on the other hand.

The plotting procedure is simplified by the use of a transparent overlay which is ruled in a vertical direction, intervals between the lines indicating a definite angular rotation of the camera. This overlay is placed over the completed picture, which will contain one or more known points

previously plotted as a control system, the overlay is oriented with respect to known points and angular differences between the known points and unknown objects measured. With a protractor, then, it is possible to transfer the angular measurement from the overlay to the plotting sheet. It is believed that this method will save time and trouble in the office, since fewer pictures are taken there will be less confusion during the plotting and more detail can be obtained from one set of pictures.

Inasmuch as the design and construction of the camera occupied a considerable portion of the time allotted to the pursuit of thesis work it became necessary to curtail work on the map project near the end of the semester. For this reason, only two pictures were taken from known points, and these on the football field at Rensselaer Polytechnic Institute. It was felt that these two pictures with the resulting map, would illustrate the problem at hand and the procedure sufficiently to prove the worth of the 360° camera.

THEORY AND DESIGN OF CAMERA

THEORY AND DESIGN OF CAMERA

Theory

It is intended to describe only those points of theory that differ from conventional terrestrial photogrammetric theory.

It is believed that the theory of the camera can best be explained by first considering a simplified camera, and altering it step by step until the actual camera is achieved.

Let us first consider a camera using a pinhole as a lens, and having its film curved along the surface of an imaginary cylinder with the pinhole on the axis of the cylinder, as in Fig. IV-1.

If a picture were made with such a camera, the picture containing objects A and B, the horizontal component of distance along the arc separating images a and b is equal to fZ, where Z is the horizontal angle, between rays to objects A and B, in radians. From elementary photographic theory, the radius f is the equivalent focal length, a term usually applied to a lens or system of lenses, but equally applicable to the arrangement illustrated.

Now let us imagine a focal plane shutter installed in the simplified camera. The focal plane shutter consists simply of a shield with a narrow vertical slit in it, placed directly in front of the film, as in Fig. IV-2.

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[illegible]

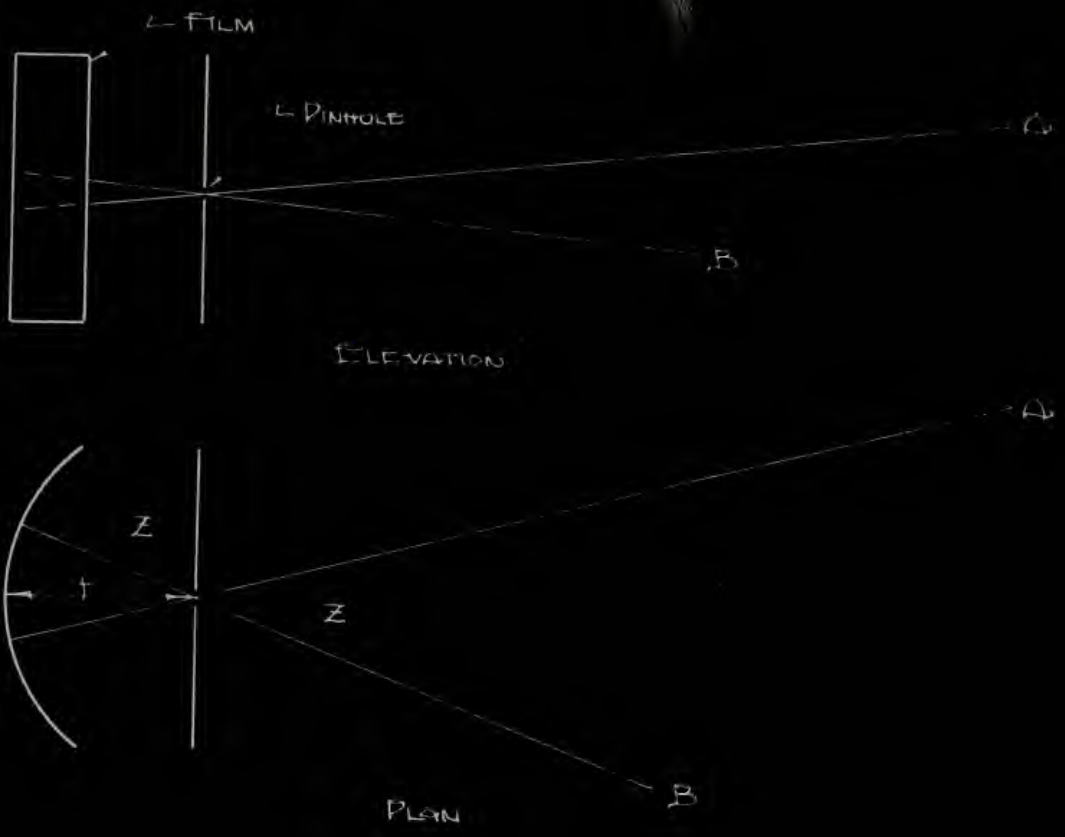


FIG IV-1

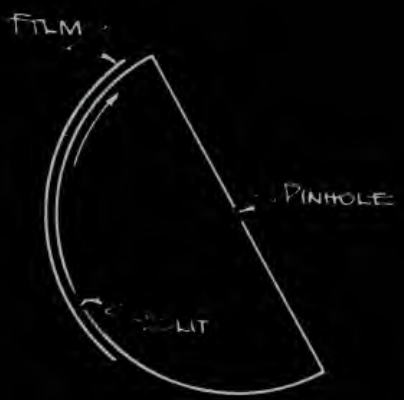


FIG IV-2

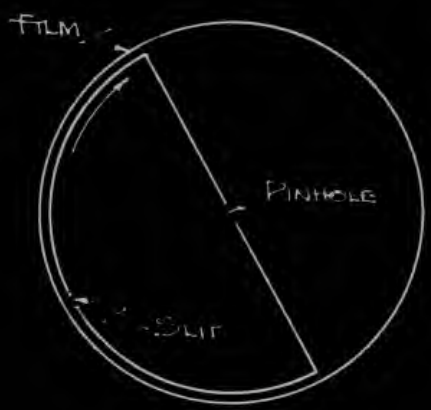


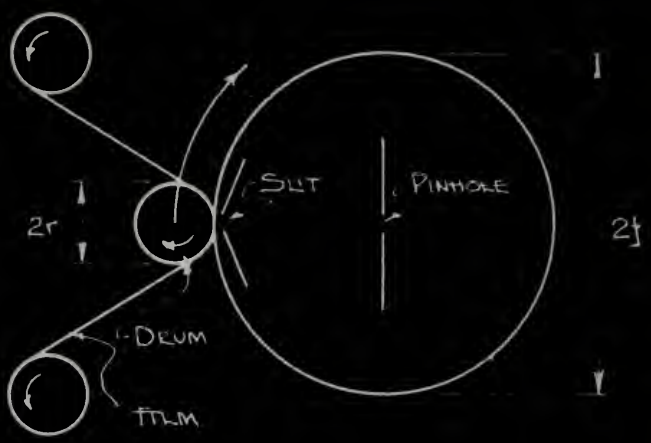
FIG. IV-3

The shutter and pinhole revolve about a vertical axis through the pinhole; the film remains fixed. It is evident that the use of a shutter of this type has no effect on the position of images, so long as the objects being photographed remain fixed.

Were it not for certain practical difficulties, we might conceive of extending the film to form a complete cylinder as in Fig. IV-3, thus obtaining a picture of all objects in the vicinity and not above or below the field of view of the camera. The length of film required to form such a cylinder would be the equivalent focal length multiplied by the angle in radians of a full circle, or $2\pi f$. Aside from the inherent bulkiness of such an instrument, the principal objection to it is the absurdity of passing light through the film on the opposite side of the cylinder from the vertical slit, the film being barely translucent and also rather light-sensitive.

Since, however, only that part of the film which is directly behind the slit is to be exposed at any one instant, the position of the rest of the film at that instant is unimportant so long as it is protected from exposure. The requirement is that the part of film being exposed have the same position and motion relative to the slit that it would have if it formed a cylinder as in Fig. IV-3.

One way to accomplish this is illustrated in Fig. IV-4. The gear of pitch diameter 2f remains fixed, while the gear of pitch diameter 2r and the film driving drum of


SLIT
PINHOLE
2r
2f
DRUM
FILM

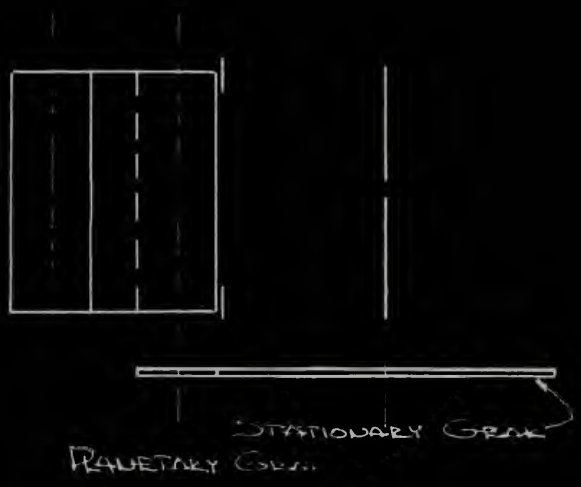

STATIONARY GEAR
PLANETARY GEAR

FIG IV-4

radius r rotate and revolve about it. Thus the film above the tangent point of the gear pitch circles occupies the same position as it would if it formed a cylinder as in Fig. IV-3.

Gears of sizes more convenient to use and more readily obtainable than those in Fig. IV-4 may be used to obtain the same effect, since so long as the gear ratio r/f is retained, the amount of film passing the slit is $2\pi r(f/r) = 2\pi f$ for one revolution about the stationary gear. The resulting dislocation of the pinhole from the center of rotation, and the fact that the curvature of film during exposure is more pronounced and opposite to the theoretically correct curvature, are of no consequence so far as horizontal distances on the picture are concerned, and have little effect on vertical distances. The substitution, for the pinhole, of a more practical lens system, and the addition of such accessories as drive mechanism, provision for levelling, film handling, light shielding, and support, complete the change from the simplified camera to the actual instrument.

Design

Fortunately, the theory developed for the camera was such as to allow considerable freedom in design, making possible the use of materials and parts most readily available.

It was decided to use a lens system of moderate speed and with a focal length of six to eight inches. A camera with an excellent f/6.3 lens system and a nominal focal length

of 170 mm. was located and purchased. The actual equivalent focal length was found to be 6.53" by a method similar to that described in a thesis by Reynolds and Chilton, Rensselaer Polytechnic Institute, 1943.

The stationary gear, its planetary gear, and the sprocket drum diameter were chosen simultaneously by trial and error to fulfill gear ratio requirements as set forth in Section IV-A, to give an integral number of sprocket teeth, for availability of gears, and for various desirable physical details. The following were chosen:

Stationary gear: 192 tooth - 6" Pitch Diameter - 32 pitch

Planetary gear: 30 tooth - 15/16" Pitch Diameter - 32 pitch

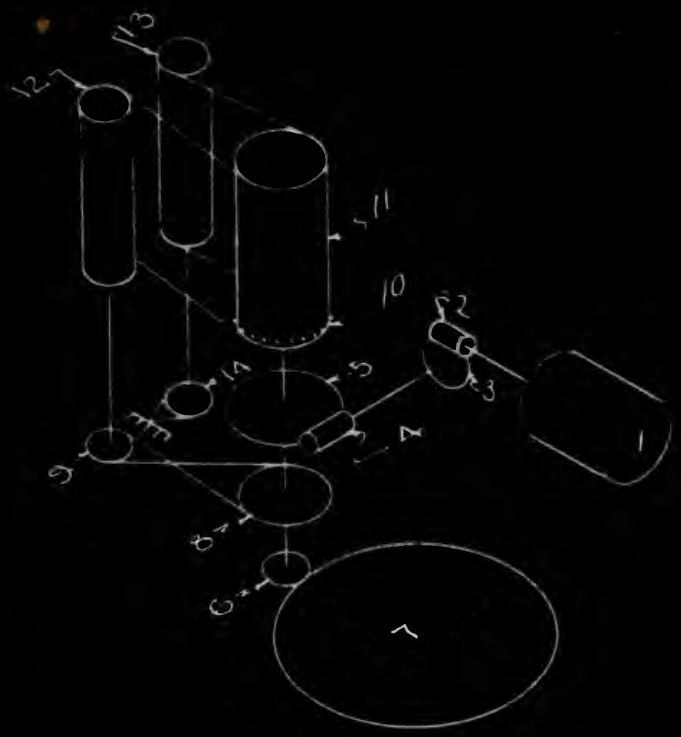
Sprocket: 20 tooth - 2.046" Drum Diameter

It will be seen that in one camera revolution, the planetary gear and sprocket will move through 192/30 = 6.4 revolution then equals (sprocket revolutions) x (number of sprocket teeth) x (center to center distance between film perforations), or 6.4 x 20 x .3214 = 41.15". Since $2\pi f = 2\pi(6.53) = 41.0$", the requirement that lenth of film per revolution equal $2\pi f$ has been fulfilled very closely. The slight difference between actual and theoretical length of film causes no error, since film length rather than focal length is used in bearing and distance computations.

It was decided that a camera rotation speed of about 2 r.p.m. would be a reasonable compromise between vi-

bration elimination and economy of time. Since the motor chosen had a nameplate speed of 5000 r.p.m., the required total gear reduction was 5000/2 or 2500/1. Since a reduction of 6.4/1 between the stationary gear and its planetary gear had been fixed, the reduction required of the remaining drive gear train was 2500/6.4 or 390/1. Actually, a 400/1 ratio was used, consisting of two 20/1 worm gear sets in series. One single thread and one double thread worm were used so that speed could be doubled or halved if this proved necessary, without resetting bearings, by merely substituting a double for a single thread set or vice versa. The time of one revolution, then, based on motor nameplate data, equalled 6.4 x 20 x 20/5000 or .512 min., or 30.7 seconds.

Trial pictures made with the Eastman Autographic Camera as purchased, using pieces of the same film intended for use in the panoramic camera to be constructed, showed that an exposure time of 1/100 second gave excellent results for expected average light conditions at approximately f/16, making the instrument capable of adjustment for light conditions brighter or darker than the expected average. The exposure time of the panoramic camera is equal to the time for one camera revolution, multiplied by the ratio of slit width to film length for one revolution. Then, 1/100 sec. = (30.7 sec.) x (slit width)/41.1", and slit width equals 41.1/30.7 x 100, or .0134". Provision was made for varying slit width from zero up to about .125" to accommodate future adjustments.



1 5000 RPM Motor
2 $\frac{3}{8}$" P.D. 1 Thread Worm
3 $1\frac{1}{4}$" P.D. 20 Tooth Worm Gear
4 $\frac{5}{8}$" P.D. 2 Thread Worm
5 $2\frac{1}{2}$" P.D 40 Tooth Worm Gear
6 $\frac{12}{16}$" P.D. 30 Tooth Planetary Gear
7 6" P.D. 192 Tooth Stationary Gear
8 2" Sheave
9 1" Sheave
10 20 Tooth Sprocket
11 2.046" Dia. Drum
12 1.25" Take-up Reel
13 1.25" Loading Reel
14 1" Sheave with Drag

Fig. IV-5. Gearing Diagram

For the sake of greater depth of field, it was later decided to increase slit width and exposure time, using smaller aperture settings. Slit width was made 1/16", bringing exposure time up to 1/25 second.

The flexible belt drive ratio was calculated so that the belt would tend to drive the take-up reel faster than the film feed would permit, thus keeping tension on the take-up end of the film. Tension is insured on the other end by a drag on the loading reel sheave. All gears and sheaves were located below the magazine to minimize the possibility of light leaks and to keep the magazine as small as possible. The gearing arrangement was designed so as to make the magazine readily removable without disturbing its light-tightness.

The overall layout of camera parts was chosen for simplicity of construction and convenience in use, rather than for conformity with standard machine design practice, outward appearance, or inherent mechanical balance. The location of batteries well forward was of considerable help in balancing the camera, placing the center of gravity above a point well within the area of the levelling head base.

Since practically all machine work was done by the authors, only layout drawings were made. Details were worked out in the shop as work progressed and mechanical tolerances were determined by feel during hand fitting operations, keeping in mind the functional requirements of the individual assemblies. For example, a slight amount of binding was tolerated in the fitting of sprocket to film, and between the

stationary gear and its planetary gear, in order to insure against backlash between film motion and camera rotation; on the other hand, the drive gear train was meshed rather loosely to insure that the motor would not be overloaded.

The design for provision of support, levelling, and light-tightness will be evident from the description of the camera in Section V-A.

Fig. IV-6 Bottom view of Film Magazine. Note relative position of shafts, sprocket drive at top, take-up reel drive on left, and method of maintaining tension on unexposed film reel.

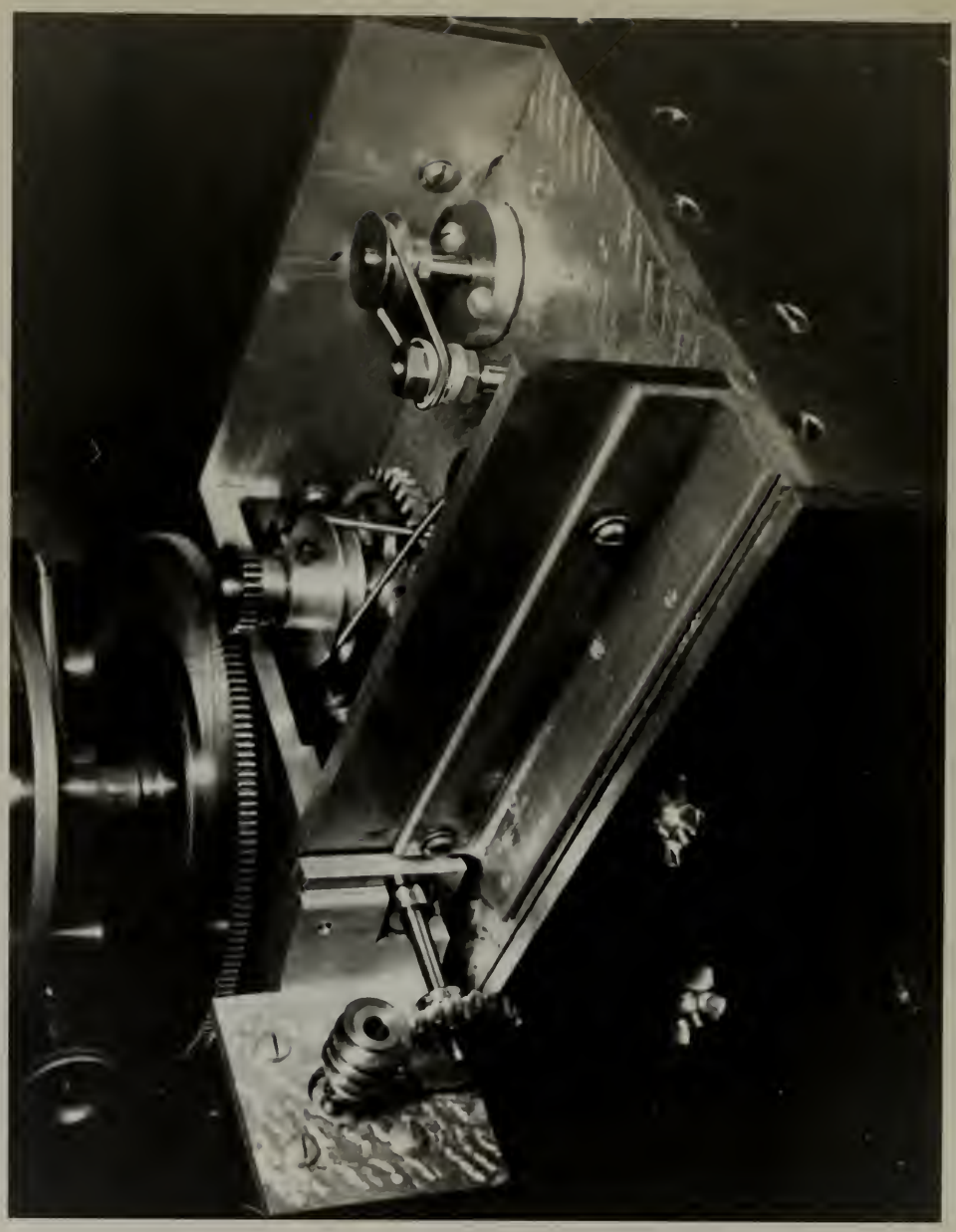
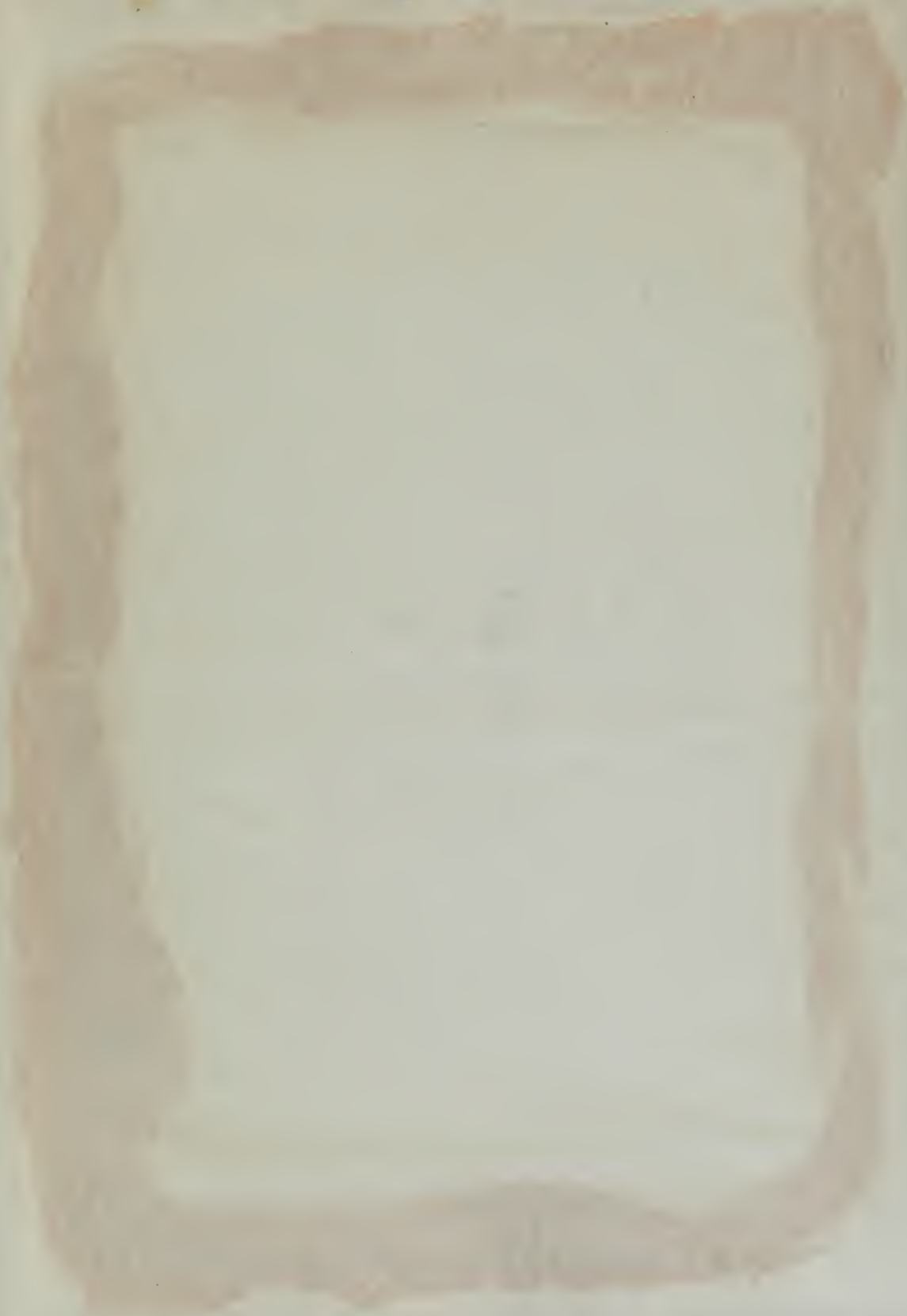


Fig. IV-7 Gear Train Assembly

Fig. V-1 Front view showing tripod and camera mounted on leveling head.



DESCRIPTION OF APPARATUS

DESCRIPTION OF APPARATUS

Camera

The word camera as used herein means the entire assembly, except for the tripod on which it is mounted, used for making an exposure. It might logically be divided into four parts, namely, lens and shutter assembly, film magazine, frame assembly, and levelling head.

Lens and shutter assembly: This consists of an Eastman Autographic camera, with an f/6.3 anastigmat lens system of nominal 170 mm. focal length, complete except for the removable back, film spools and fron catch. A stop was installed for ease in focusing at infinity; a gasket was added to the rear to eliminate light leaks between it and the film magazine.

Film magazine: This consists of a box fabricated of 1/4" 61 ST Aluminum, assembled with aluminum angles and screws. The box is roughly an eight inch cube. The two sides are gasketed and secured with wing nuts of easy removal and assembly in the darkroom. The front has an opening for admission of light from the lens system, and clips for holding the Eastman Camera in position. On top are the level vials and three bearing caps which hold the bearings in place and exclude light. Inside at the rear are two film reels mounted vertically; forward of the film reels is the sprocketed drum. A shield with a slit of adjustable width is mounted directly in front of the drum. The shield is mounted

Fig. V-2 Camera mounted on leveling head, bellows extended and cable release and motion switch connected.

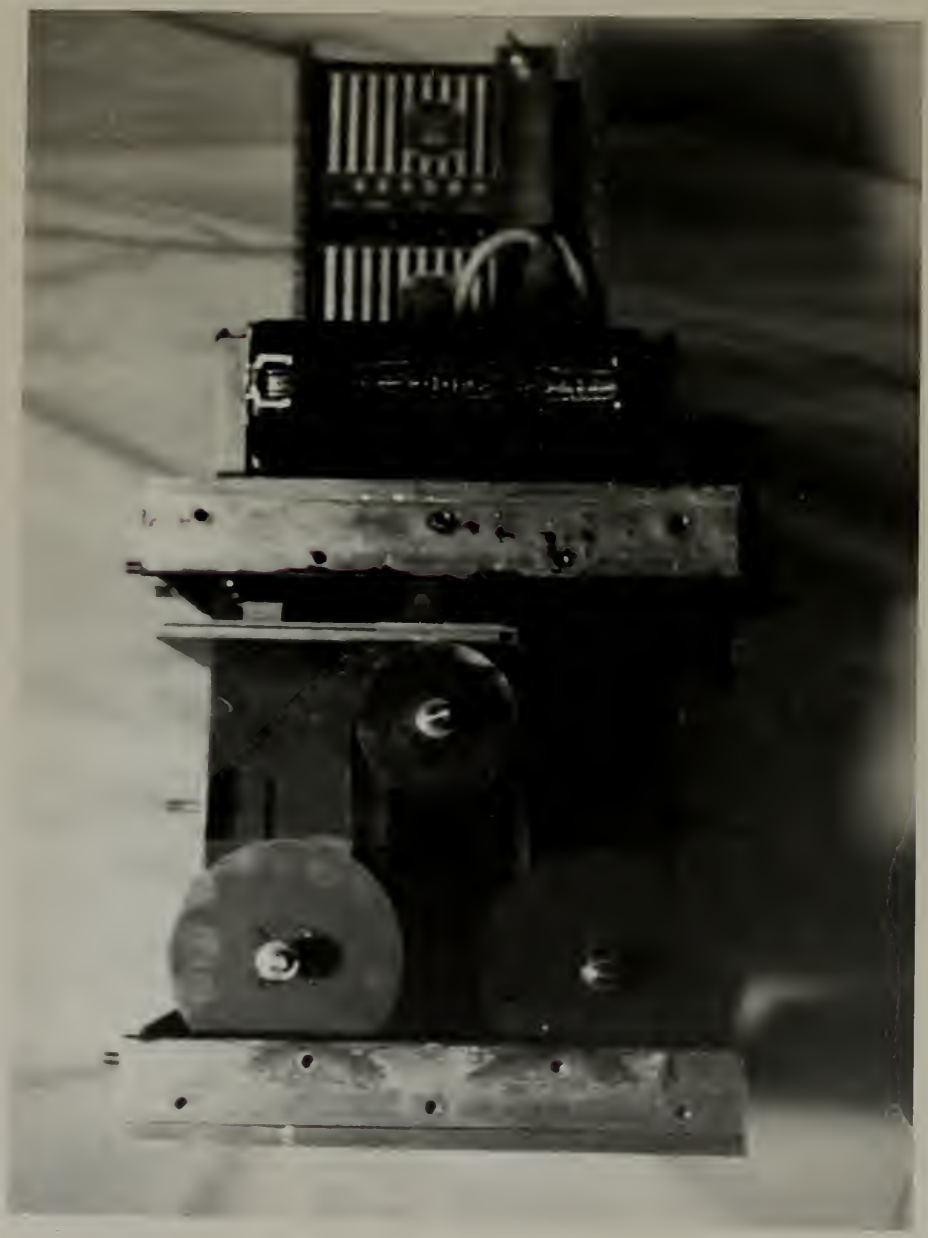


Fig. V-3 Top view of Film Magazine. Note plate containing focal plane slit bearing against sprocket drum.

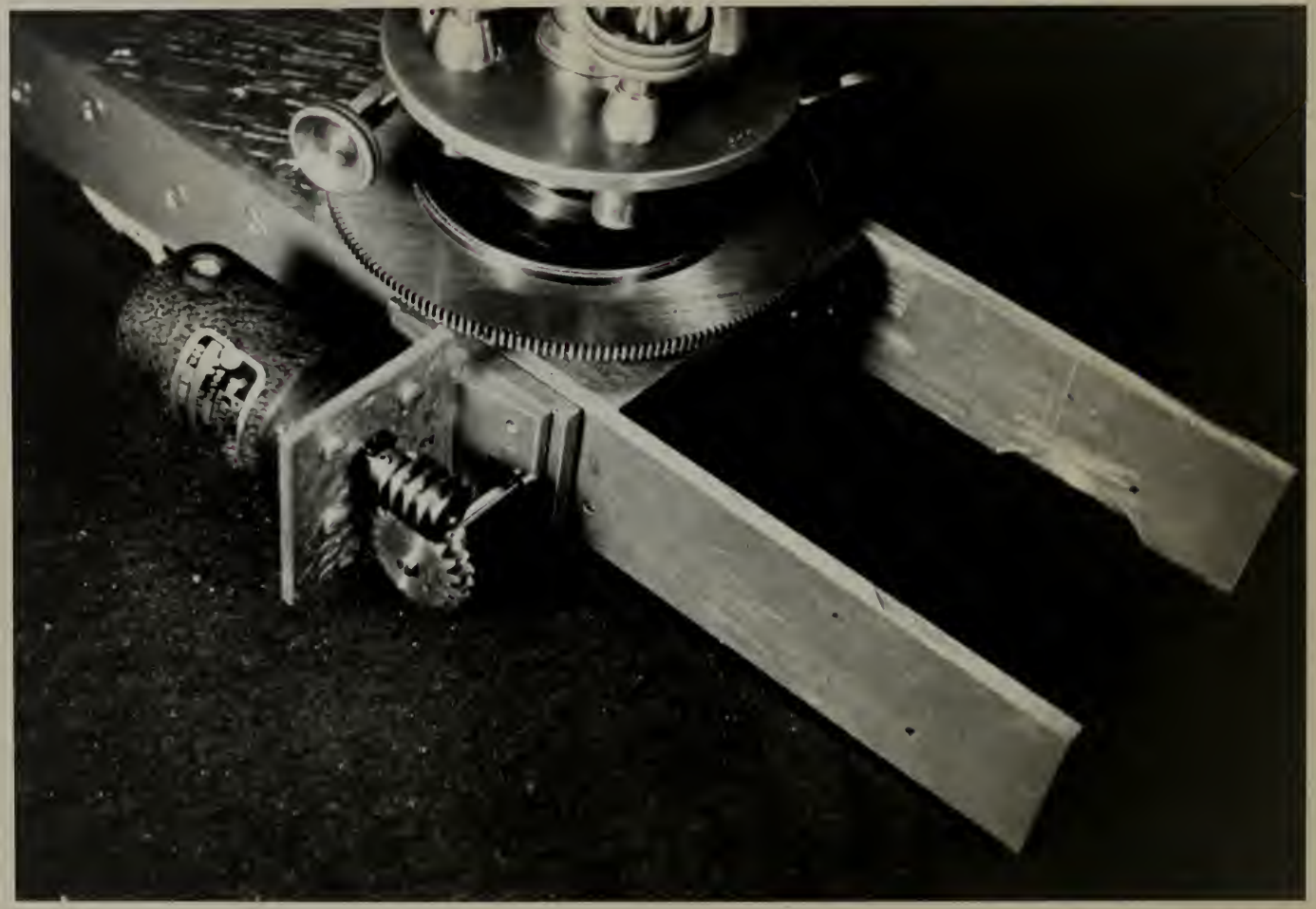


Fig. V-4 Bottom of frame assembly showing motor mounting and bull gear fastened to leveling head.

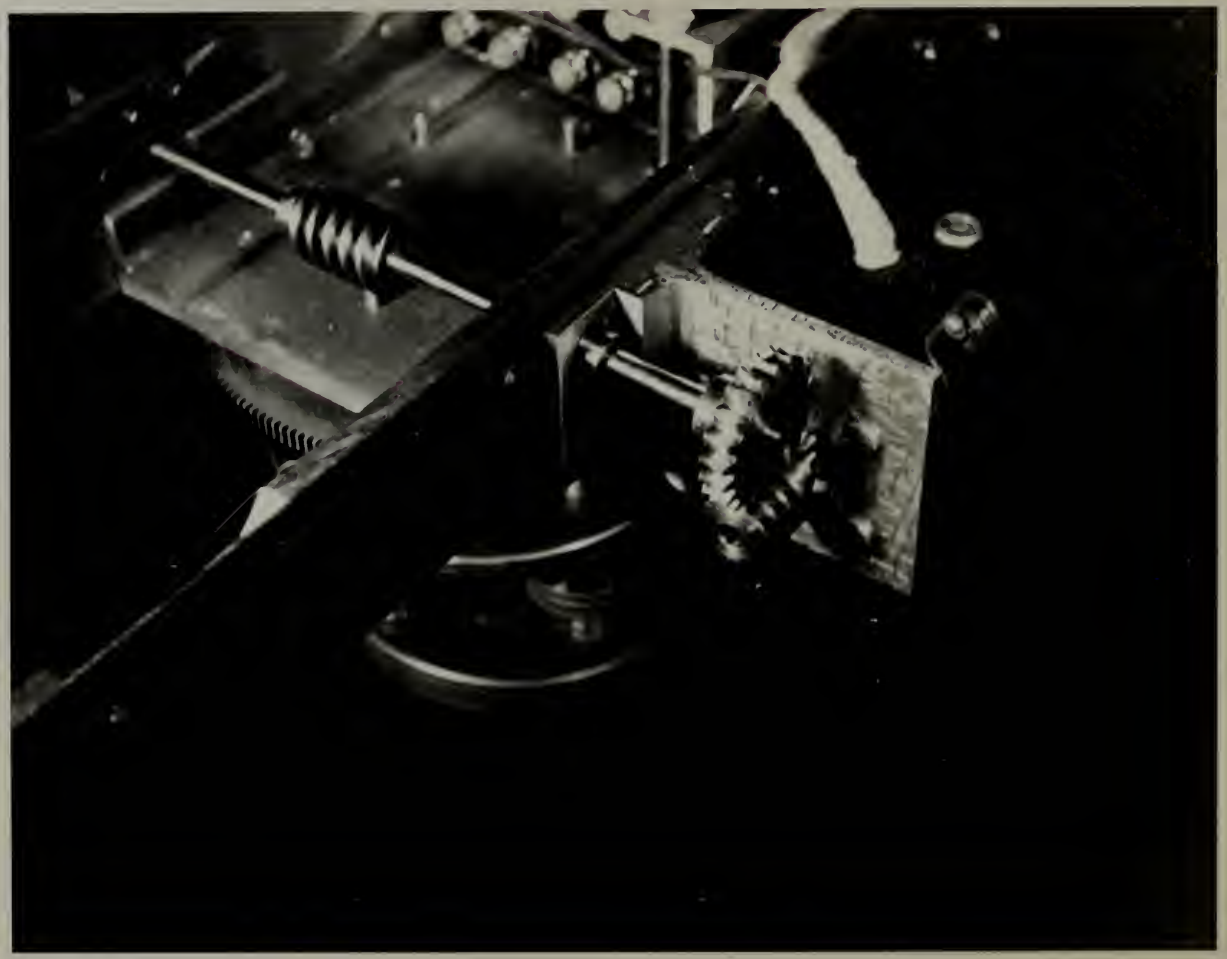


Fig. V-6 Top of frame assembly showing partial gearing.

on vertically axed hinges at one side, and a bellows of rubber connects the vertical slit and the opening in the front of the magazine, and also holds the shield against the film during operation.

The shafts of the reels and sprocketed drum extend through bearings below the bottom of the box. The reel shafts carry sheaves for maintaining film tension as previously described. The drum shaft carries a sheave which is belted to the take-up reel sheave with a flexible belt. The drum shaft also carries a worm gear which, when the magazine is mounted, meshes with the second worm of the drive gear train. The drum shaft also carries the planetary gear which mates with the stationary gear.

The inside of the magazine and parts mounted therein have been blackened either by a chemical process or by painting, depending on whether or not their dimensions were critical.

Frame assembly: The frame consists of two side plates held by angles to a bottom plate. Its purpose is to transmit the loads from the magazine, lens assembly, drive mechanism, and batteries to the leveling head. The batteries which supply the motor are mounted well forward between the side plates. The motor is mounted on the right side plate, and its shaft carries the first worm of the driving train. The ball bearing mounted cross shaft extends through the right side plate to carry a worm gear which meshes with the motor worm. On the cross shaft, midway be-

twoen the side plates, is the second worm of the driving train, which, when the magazine is mounted, meshes with the worm gear mounted on the drum shaft. The motor is provided with a push button switch at the end of the flexible leads, to which is secured a removable cable release for the camera.

Leveling head: This is simply a standard, fairly rugged leveling head from an antiquated transit, stripped down to expose the top of the flange of the upper motion taper. The bottom plate of the frame is secured rigidly to this flange. The upper motion taper then turns as the camera rotates in operation, the lower motion remaining clamped except during the leveling operation. The stationary gear is fitted to a projecting ring at the top of the flange of the lower motion taper.

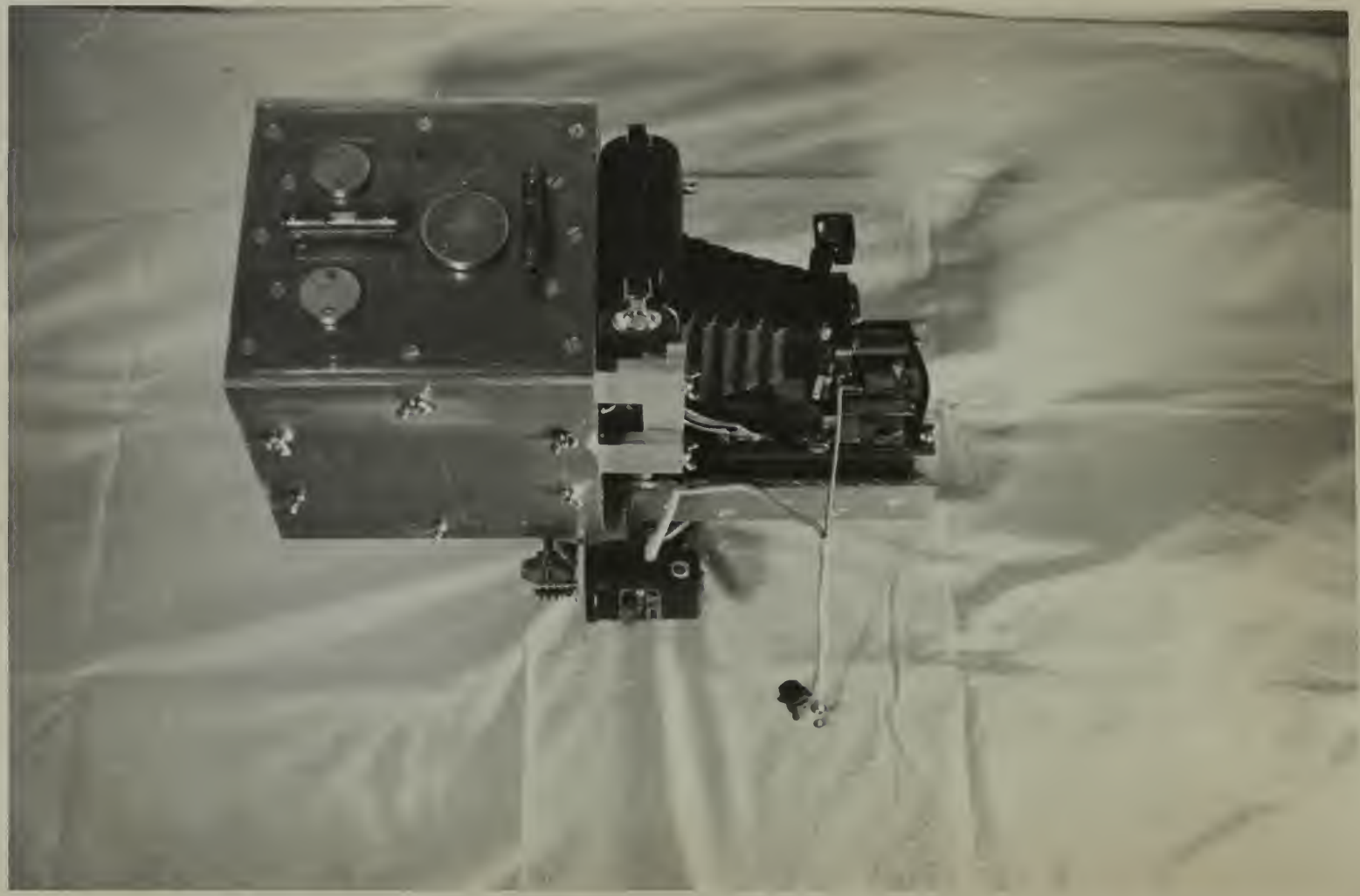


Fig. V-6 Top view of camera showing bellows extended Note level vials on top plate and top bearing caps.

B. Field Equipment

The field equipment described herein refers only to that equipment actually used in conjunction with the 360° camera and not any additional that may have been used in the laying out of control. Since control may be laid out in any one of several ways, it is felt that a discussion of such work is outside the scope of this thesis.

In addition to the camera itself, the following pieces of equipment were used:

One Standard surveyors field notebook.

Range poles to be used as targets, equipped with white cardboard tacked near the top of the range pole to aid in identifying it in the picture.

Exposure meter.

Flexible steel rule.

Plumb bob, pencils, etc.

Since the camera as assembled on the tripod is a rather heavy piece of equipment, weighing about 45 pounds, to be moved readily, it was found that three men form the best party when working in the field. These might be classed as Photographer, whose duty is to care for the camera, levelling taking the picture, supervise the placing of the targets, and see that the camera is properly transported to the next location; Notekeeper, whose duty is to take comprehensive notes on each station occupied, light conditions, height of instrument, lens opening used, and aid the Photographer in

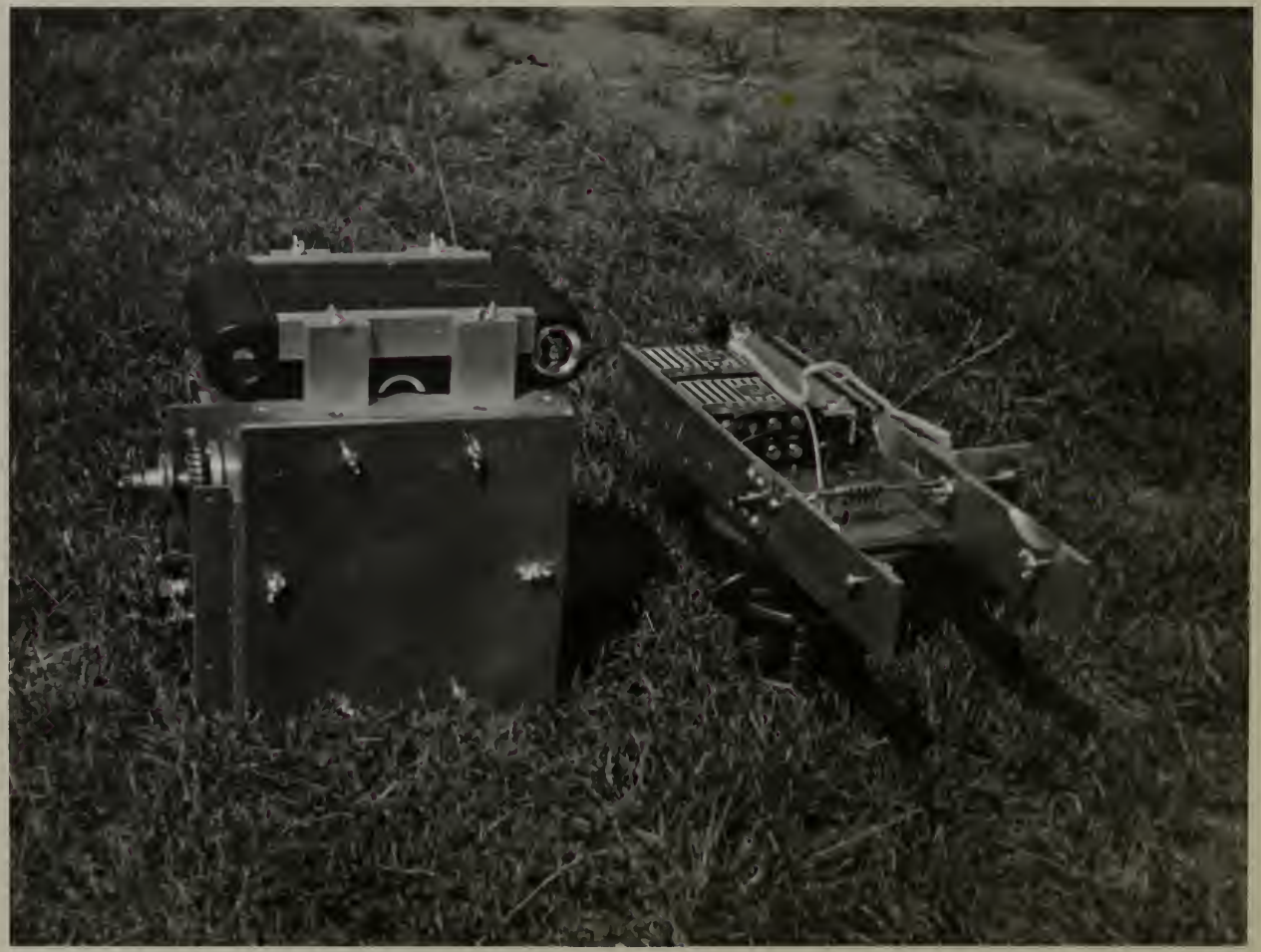


Fig. V-7 Film magazine and frame assembly in field. Note camera in closed position.

the transportation of the camera; Assistant, whose duty is to place the targets as directed by the Photographer and maintain them in such a position that they will produce a readily identifiable image on the print.

C. Darkroom Equipment

As previously noted in the section of Theory and Design of the Camera, one of the factors in the design was the width of available film. Since this film was about twice the width of the film which was to be used in the camera, a cutter was developed which could be used in the darkroom and yet cut the film with sufficient accuracy to be used in the film magazine without further trimming. Although this cutter has no part in the processing of the film, it was thought that it should be mentioned in the event that available commercial film does not fit the sprocket drum or the film reels in the film magazine.

In addition to the cutter, the following items were used:

Government surplus film developing unit, with set of three nesting stainless steel tanks and reversing reels.

Three white enameled trays, 11" x 14".

Large piece of plate glass for making contact prints, about 12" x 40".

Toweling, or other material for placing under the plate glass to insure good contact between the printing paper, film, and glass.

Timer, measuring graduate, stirring rod, thermometer, and blotters.

The chemicals used in processing the film and paper were commercial products, readily obtainable at any

Photographic Supply store.

For film, D-76 type developer and Acid Hypo with Hardener were used.

For the prints, Microdol, a D-72 type of developer, Shortstop with an indicator, and Acid Hypo with Hardener were used.

The paper used for the prints was Azo F-2, single weight, smooth, glossy, in a roll 18" x 30'. This provided enough paper for twenty four prints with sufficient paper left over for test strips. The original intent was to use double weight paper, but this was unobtainable at the time.

D. Mapping Equipment

Mapping may be performed using none other than standard drafting equipment. Additional items which were found helpful were two transparent overlay grids divided horizontally into 360 equal divisions in 41.15". One division then equals one degree.

Since the method of determining elevations is the same for this type of equipment as for conventional equipment used in terrestrial photogrammetry, no elevations were plotted and the grid was not divided vertically. Recommendations concerning procedure in determining elevations, however, are included in the section on recommendations.

CALIBRATION

CALIBRATION

1. Focal Length Determination

Two methods were used to determine the focal length of the lens system used. Inasmuch as the focal length played an important part in the design of the camera, it was necessary to determine it with a fair degree of accuracy. This was done in one instance by direct measurement, focusing on an object far enough from the lens to be considered at infinity and measuring the distance from the lens to the ground glass focusing screen. A check on the focal length as determined in this way was made by taking a picture with the camera focused at infinity, measuring the actual distance between two objects in the picture, the distance from the camera to the objects, and the distance between the images of the objects on the film. Knowing this data, the focal length may be computed using similar triangles.

Data for these focal length determinations appears below:

	Direct Measurement			
	1	2	3	Av.
Back Focal Length	6.08"	6.06"	6.07"	6.07"
Front Focal Length	7.36"	7.35"	7.35"	7.35"
cd	1.35"	3.40"	2.42"	
ab	.57"	2.11"	1.14"	

Chapter One

1. Local Search Preprocessing

The machine does not do decimation for local
length of the local physics model. Compared to the Visual
Length Graph on Decision Data 1, the density of the network
is not necessary. In comparing it with a Data Volume of Van-
couver. Only one data is not Database of Every Consumer,
Changing or be Modern try model. Some the Data to be obse-
rvation at Half-Up and consistent the Database Once the Com-
be the Format Local Operating Answers. A Model on the Comp-
length be Determined In this by the Model by Making a Obse-
lines with the Volume Possible Of Current, Computing the Ma-
tual Changes Between the Objects in the Library. The Diffe-
rence Three the Volume to the Objects and the Standard De-
pends its Length of the Problems to the Files. Looking Data
Study, the Local Length may be available Data Similar Data-
sets.

Here the Close Local Length Determination Algo-
rithm Decision

Query Environment

Some Model Design	4.208	6.208	8.477	1.477
Check Visual Length	7.384	7.484	7.484	7.484
as	1.488	8.484	8.488	
as	.484	8.477	7.488	

$$\frac{6.07 + 7.35}{2} = 6.71\text{" Average Focal Length}$$

Picture Plane Method

Two pictures taken from which the following data were obtained.

	ab	cd
Negative #1	3.86"	.34"
Negative #2	3.86"	.34"

$\frac{ab}{fl} = \frac{159.9}{270.0}$, $fl_1 = 6.52"$, $fl_2 = 6.52"$

$\frac{cd}{fl} = \frac{18.70}{360.0}$, $fl_1 = 6.55"$, $fl_2 = 6.55"$

$$\frac{6.55 + 6.52}{2} = 6.53\text{" Average Focal Length}$$

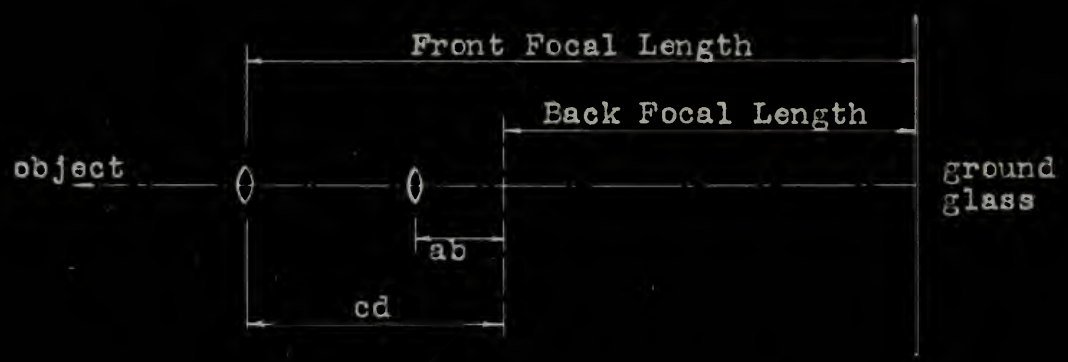


Fig. VI-1. Focal Length Determination by Direct Measurement.

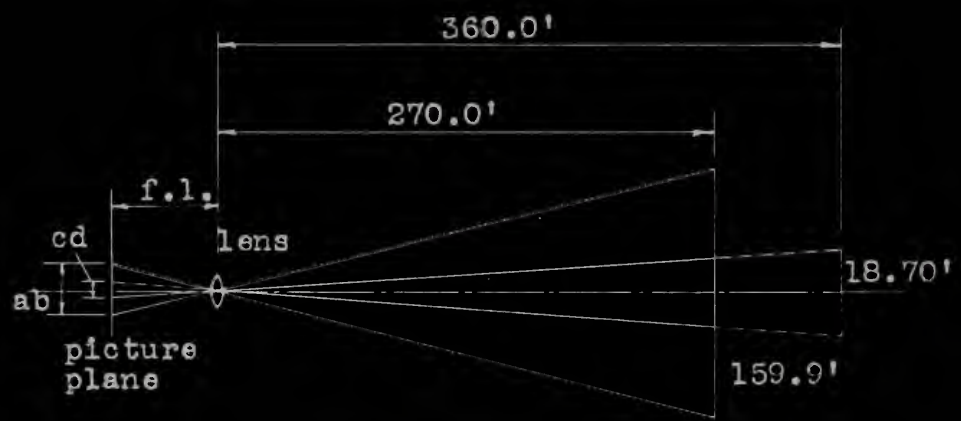


Fig. VI-2. Focal Length Determination by the Picture Plane Method.

2. Film Speed Determination

Since the film to be used was known to be Aero type, it was assumed that it had a fairly fast emulsion. In order to find the approximate speed of the emulsion several strips of test film were exposed in a camera, similar to the one used on the 360° unit, at varying lens openings, the shutter speed remaining constant. Unfortunately, no exposure meter was available during this run, hence no evaluation of light intensity was made other than could be observed.

7, April, 1948, 2:30 pm, clear and bright, medium sun.

Test Strip	f Value	Shutter Speed
1.	8	1/100th sec.
2.	11	1/100th sec.
3.	16	1/100th sec.
4.	22	1/100th sec.
5.	32	1/100th sec.
6.	64 (approx.)	1/100th sec.

Developed in M.Q. Developer, 11 minutes at 69° F.,
Washed in water for 2 minutes.
Fixed in Acid Hypo for 8 minutes.
Wash 30 minutes in running water: Dry.

Results: Settings at f/11, f/16, and f/22 produced good definition and detail with best results at f/16.

3. First Trial Run

26, July, 1948, cool with high overcast, sun

9. Title Bout Determination

Bouts are title bouts when agreed to by both fighters, or when a fighter's name appears in the ratings. In order to lose a title by decision, a fighter must be defeated by a margin of at least two points on all three scorecards. Otherwise, the champion retains the title.

10. Time Limit Determination

Bouts are scheduled for [illegible] rounds, depending on the weight class. Championship bouts are [illegible] rounds. Bouts may be shortened by [illegible] with the consent of both fighters and the referee.

11. Weight Classes

Weight Class	Limit	Championship
Flyweight	112 lbs.	Yes
Bantamweight	118 lbs.	Yes
Featherweight	126 lbs.	Yes
Lightweight	135 lbs.	Yes
Welterweight	147 lbs.	Yes
Middleweight	160 lbs.	Yes
Light Heavyweight	175 lbs.	Yes
Heavyweight	Unlimited	Yes

Overweight by [illegible]: [illegible] allowance of [illegible]
Varied by mutual [illegible]
Fined [illegible] per [illegible]
Over [illegible] pounds [illegible]
Championship [illegible] at [illegible] [illegible] and [illegible]
[illegible] bout [illegible] [illegible] [illegible]

12. Time Limit Fee

[illegible] [illegible] [illegible] [illegible]

breaking through intermittently, light shadow. Camera location, approximate center of football field, Rensselaer Polytechnic Institute. It was decided to change the lens opening about every 60° of angular rotation to check on the correct opening for this light condition.

f value	Area Covered
6.3	Hill, Dining Hall, and East end of football field.
8	East end and center of brick bleachers.
11	Center and West end of brick bleachers.
16	Greene Building and West end of foot ball field.
22	Sage Building, and Troy Building.
32	Ricketts Building.
64 (approx.)	Gym and East end of football field.

Developed in D-76 eight minutes at 78° F.

Wash three minutes in running water.

Fix ten minutes in Acid Hypo.

Wash thirty minutes in running water. Dry.

Negative: Best results obtained from lens opening of f/16. Useable negative from f/11 to f/22, however, if care is used to vary exposure when making contact print.

4. Second Trial Run

The second trial run was made for the purpose of determining the true horizontal axis of the camera. This

Cards	Description
1	Card and end marker of Control Cards.
12	Number and type of Control Cards.
12	Number of Control Cards.
24	Type of Control Cards.
24	Number of Control Cards.
24 (Binary)	Type and Card of Control Cards.

was done by scribing lines on a piece of transparent material and securing this to the aluminum plate forming the focal plane slit in the approximate location of true horizontal. The trial location was determined by careful estimation of the picture obtained from the first trial run, knowing the location, approximate height of the camera, and height of the front brick wall of the bleachers.

Location: Football field, R.P.I., 26, July, 1948, hot and clear. Light value: General Electric light meter type DW-58, cover closed, 10 foot candles.

Equipment: Precise level No. 148, two level rods, camera.

Procedure: Determine height of level, height of camera, secure one level rod at each end of football field and set targets to correspond to the height of the lens of the camera.

Data: Height of level 4.864'

Height of camera 4.805', D.N. .059'.

Lens setting, f/16

It was found that the line corresponding to the true horizontal axis of the camera was the fourth line from the bottom line of the lines inscribed on the transparent material in place rather than attempt to reset the correct line after removal of the others.

5. Third Trial Run

Made for the purpose of acquiring data for plotting of a map, but due to errors in setting up and operation of the camera the data obtained had to be discarded.

6. Fourth Run

Made for the purpose of acquiring data for plotting map. 13, August, 1948, overcast and light sun, warm and sultry.

Location: Football field, R.P.I.

Data: First set-up. Occupied B.M. A-3 at west end of football field. Light condition 20-25 fc. H.I. 4.9'. Lens Opening f/16. Target at B.M. B-3. White card on range pole. Camera operated for full revolution.

Second set-up. Occupied B.M. B-3 at east end of football field. Light condition 20-25 fc. H.I. 5.0'. Lens opening f/18. Target at B.M. A-3. White card on range pole. Camera operated for full revolution.

Developed in D-76 fifteen minutes at 70° F.
Wash two minutes in running water.
Fix seven minutes in Acid Hypo.
Wash forty five minutes in running water. Dry.

On examination the negatives seemed satisfactory but an attempt at printing showed sufficient over exposure on the first set-up, A-3, to make a retake advisable.

7. Fifth Run

Made for the purpose of obtaining a better negative than was obtained from the fourth run on occupying B.M. A-3. 15, August, 1948, bright sun, warm.

Location: Football field, R. P. I.

Data: Occupied B.M. A-3 at west end of football field. Light condition 25 fc. H.I. 4.7'. Lens opening f/22. Target at B.M. B-3, white card on range pole. Camera operated for full revolution.

Developed in D-76 fifteen minutes at 72° F.

Wash ten seconds in running water.

Fix eight minutes in Acid Hypo.

Washed one hour in running water. Dry.

The negative from this run produced better pictures than that from run four.

From records in the Department of Civil Engineering, bearing from B-3 to A-3 235° 42' 20". Distance 510.93'.

PROCEDURES

PROCEDURES

A. Care and Operation of Camera

The precautions commonly exercised in handling and storing surveying instruments and photographic equipment are applicable to the camera; that is, excessive shocks and exposure to extremes in humidity and temperature are to be avoided, and the instrument should be kept clean and well lubricated. The only parts that may require care other than is readily indicated by their nature are the gears, sprocket, and leveling head tapers.

Due to their exposed position and the fact that some of them are of steel, the gears may tend to collect dirt and rust. A coating of medium grease containing a rust inhibitor will prevent rust at ordinary temperatures. The gears should be kept scrupulously clean, since particles of foreign matter in them can cause roughness in camera operation with resultant light streaks in the pictures. Ordinary medium oil is satisfactory lubrication for the gears.

Oil has not been found satisfactory for lubricating the leveling head taper. Due to considerable weight of the camera parts above the leveling head, a medium to heavy grease was used and considered satisfactory for this purpose.

No special care need be accorded the sprocket unless for some reason it is removed from the film magazine. In that case considerable care must be taken to avoid damaging the teeth, which are of aluminum and therefore quite soft.

It is recommended that the leveling head and frame units be kept assembled together at all times, likewise the lens and shutter assembly and film magazine.

Procedure for setting up and operating the camera is as follows:

1. Set up tripod.
2. Mount leveling head and frame assembly on tripod.
3. Locate over control point, using plumb bob.
4. Mount magazine and lens assembly, taking care not to damage the gears in meshing.
5. Check gear mesh by turning motor over by hand.
6. Open camera and extend bellows until positive stop is reached.
7. Insert cable release in shutter mechanism.
8. Set shutter control to time, "T" on lens housing.
9. Cock shutter and push cable release twice in rapid succession to check operation. This operation will overexpose about 1/16" of film, but the assurance that the shutter is operating is well worth it.
10. Recock shutter.
11. Adjust aperature.
12. Level instrument with lower motion unclamped, and set at desired starting point.
13. Clamp lower motion.

14. Standing at the right hand side of camera, operate cable release and motion switch as near simultaneously as possible. The operator can keep out of the field of view by walking to one side or behind the camera while it is in operation. When the instrument has completed a full revolution, or the desired part of one, again push switch and cable release, stopping the motion of the camera and closing the switch.

E. Darkroom Equipment

1. Cutting Film

Since all of the cutting operation must be done in total darkness, it is essential that the position of all equipment used be carefully noted to prevent confusion and loss of time. The 12" reel of uncut film is best placed in the cutter so that the emulsion (dull) side is up as the film passes under the cutting bar. Raise the cutter bar and draw the uncut film toward the empty reels, passing it under the empty reels until about five inches extends beyond the edge of the cutter base. Lower the cutter bar, clamp, and pull the film by hand toward the empty reels until the slit sections of the film come to about the edge of the cutter base. With scissors or a sharp knife cut the excess portions of the film away, leaving the two six inch strips to be fastened to the empty reels and the small strip one quarter of an inch wide that comes from between the cutter blades.

Thumb tack the six inch strips to the empty reels, emulsion side facing inside, and start turning the crank counterclockwise. At the same time, pull the quarter inch strip toward the empty reels to help clear the cutter blades. This is very important, since any stoppage of the small strip will clog the cutter blades and tear the film. If the turning of the crank is maintained at a steady and even rate, the cutting should proceed rapidly and without trouble.

When sufficient film has been placed on the reels,

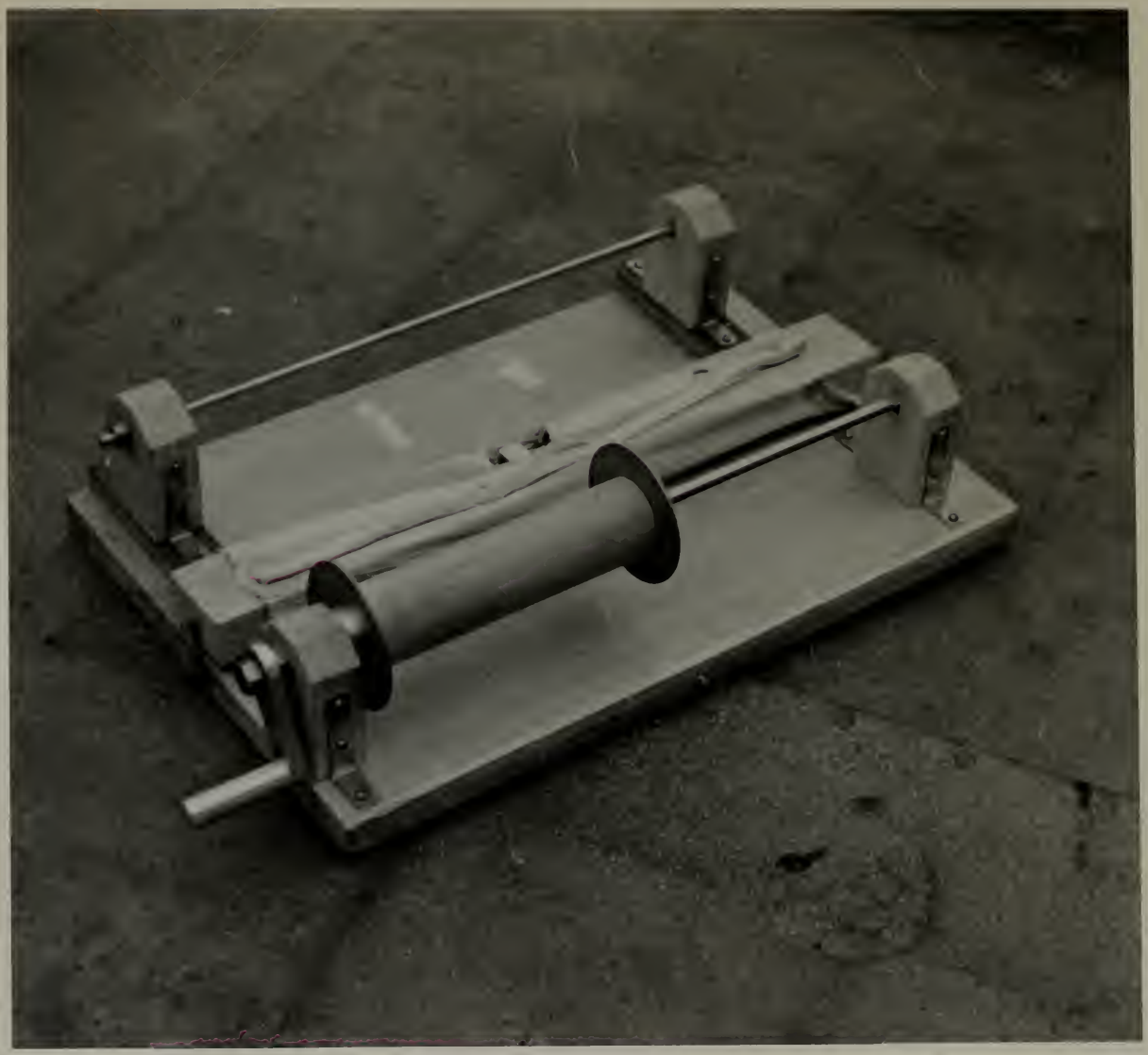


Fig. VII-1 Film Cutter

cut the film free, remove the reels from the crank shaft, and store the film in a light tight container.

2. Developing the film

The developing process must also be done in total darkness until the film has been in the Hypo for about five minutes after which the lights may be turned on. This necessitates orderly placing of the developing equipment so that the film may be easily moved from one tank to the other without loss of time.

With the equipment in position and solutions in the tanks, remove the sides from the film magazine and load the reversing reels that form part of the developing unit. Start the timer and place the reels in the tank containing the developing solution. Rotate the reels so that the film is continuously moving from one reel to the other, at a fairly uniform, slow speed. After the developing time is completed, raise the reel unit from the developing solution and allow the excess to drain back into the tank. Place the film and reels into the wash tank and allow to wash with running water for about two minutes, then remove and drain. Next, place the unit in the Hypo to start the fixing process, after about five minutes the lights may be turned on and the film examined. Continue the fixing process for about ten to fifteen minutes, depending on the freshness of the Hypo. Remove from the Hypo, drain, and wash in running water for about forty minutes.

After the film is washed, remove from the reels, hang up by the use of clips, and remove the excess water with a photo sponge.

Experience has indicated that the most convenient length for drying is a little over six feet, or two pictures. If the reel developed contains more than two pictures, the film should be cut into two picture sections as it is removed from the reel for drying.

3. Printing

In the making of contact prints, the authors found the easiest method was to use a piece of plate glass somewhat longer and wider than the negative, and the light used as general illumination in the darkroom for the light source. A large towel was placed under the glass to provide good contact between the paper, film, and glass. This was necessary due to the unevenness of the table top upon which the pictures were printed.

The solutions were placed in three white enameled trays approximately 11" x 14" in size, and the prints run through the solutions by hand. This was found entirely adequate and satisfactory since the density of the resulting print could be closely controlled by watching the images come out under a ruby or amber safelight.

No attempt was made to keep data on the length of exposure, or time of development, since this will vary with the density of the negative, the strength, location, and position of the light source, and the strength of the developer.

The best way to check for these factors is to use a test strip of paper and process it in the usual manner. Fixing was usually carried on for about ten minutes as this time was found sufficient for the purpose of the prints. Although the authors had no trouble with the fixing bath, it is good technique to check the bath with a test kit every so often to be sure that the fixer has not been exhausted.

4. Loading the camera

This assumes that the film has already been cut to the correct width for the film spools in the film magazine. The authors followed the procedure of allowing about a foot for leader and a foot for trailer which gave plenty for clipping to the reels of the developing machine. With this in mind, and remembering that all the loading operations must be done in total darkness, proceed as follows:

Lay the film magazine on its back with the top facing the operator and remove the two side plates. Check the motion of the reels and sprocket drive drum by turning over by hand.

With the correct length of film ready to load, fasten the film to the left hand reel with two pieces of scotch drafting tape, emulsion side toward the reel. Make sure that perforations in the film are adjacent to the bottom flange of the reel.

Turn the reel in such a direction as to wind the film on to the reel. During the winding operation it may be advisable to remove the tension spring from the shive, but

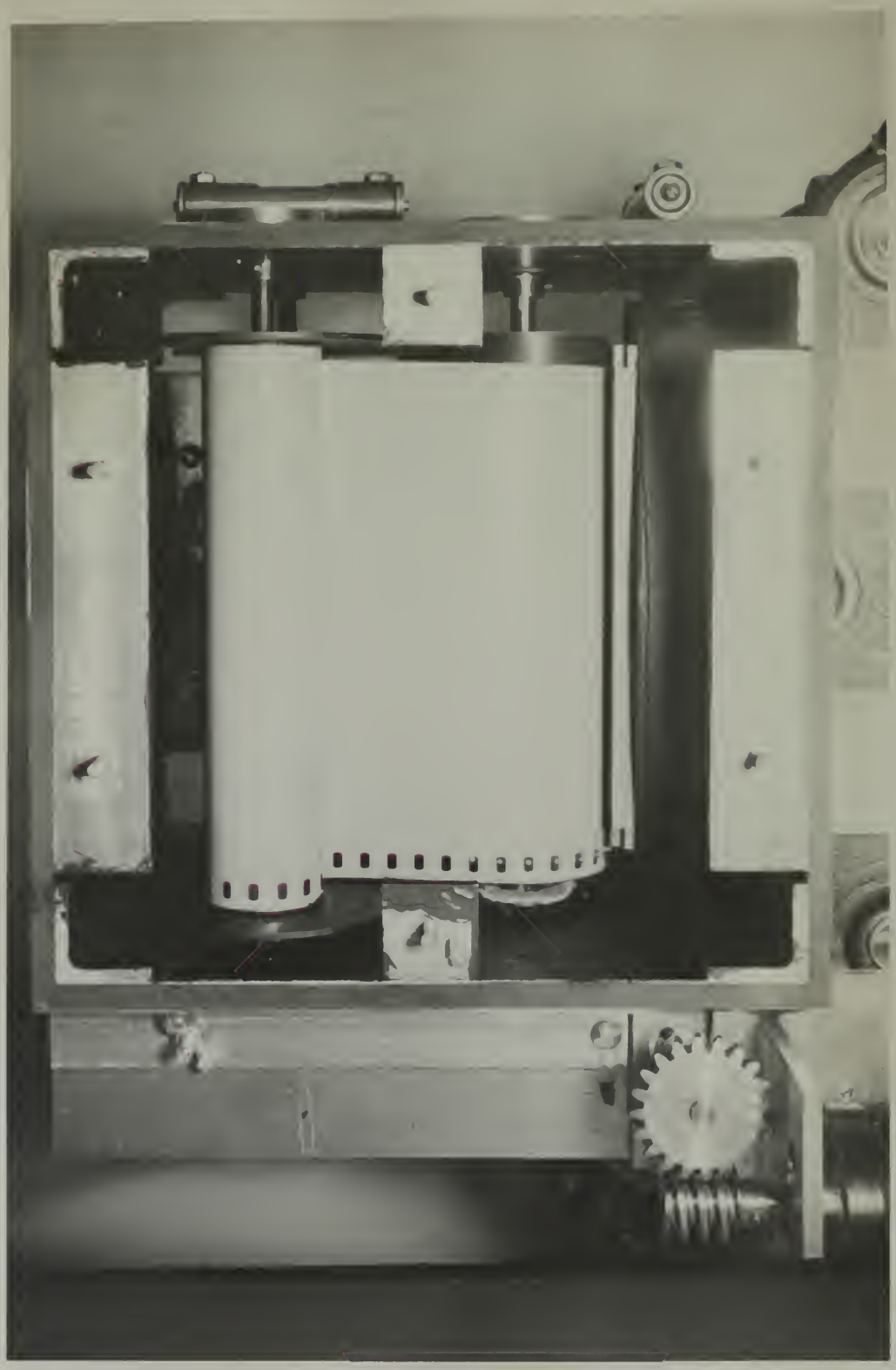


Fig. VII-2 Side view of camera with side plates removed showing film in position around sprocket drum and take-up reel.

as soon as winding is completed, replace the spring or the film will have a tendency to unwind from the reel.

With a pair of scissors, cut off about the first eight inches of the perforations and slide the film between the plate forming the focal plane slit and the sprocket drum. This may be facilitated by pressing the focal plane slit slightly toward the front of the camera.

Draw the film through until the perforations engage the sprocket teeth, then secure the film to the take up reel in the same manner as previously described, emulsion facing the reel.

By hand, turn the small gear fastened to the shaft of the sprocket drum in the same direction as it will turn when the camera is in operation. Check the take up reel to see that film is being handled correctly.

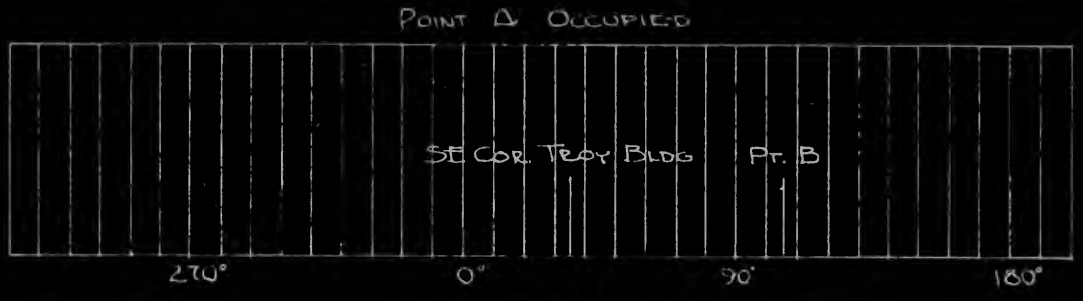
Replace the side plates and tighten the thumb nuts securely by hand. The film magazine is now ready for operation.

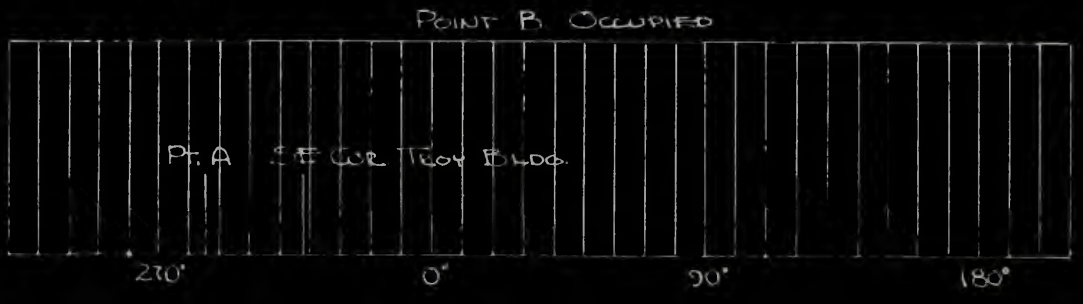
C. Plotting

All control points from which exposures have been made are first plotted on the map sheet by the use of coordinates or any other standard method of plotting control.

Prints of pictures made at two adjacent stations are then secured to a drawing board over a backing sheet. Each print contains at least one object of known bearing; the grids are therefore placed over the prints so that this object falls at the proper distance from a vertical grid line to permit the grid lines to represent even degrees of true bearing. For example, if a known object were at bearing 36° - 30', the known object should be located halfway between two vertical lines. The vertical lines are then identified every five or ten degrees by noting the bearings the lines represent on the backing sheet. (If the divisions were labelled on the overlay grids, the grids would almost surely have to be transferred during plotting or grids nearly seven feet long would have to be use.)

Any other point may be located on the map by simply reading the bearing from the first picture and grid, and plotting a line of that bearing from the control point on the map from which that picture was taken, then reading the bearing of the same object from the second picture and grid, and plotting its bearing from the control point from which the second picture was made. Other points are located until the map is completed. It is recommended that any one object be located completely on the map before plotting bearings to





DISTANCE A TO B = 510.93'
BEARING A TO B = 105°-42'
FROM POINT A, BEARING TO SE CORNER TROY BLDG. = 34°-40'
FROM POINT B, BEARING TO SE CORNER TROY BLDG. = 319°-00'
SE CORNER TROY BLDG. THEN LOCATED BY INTERSECTION

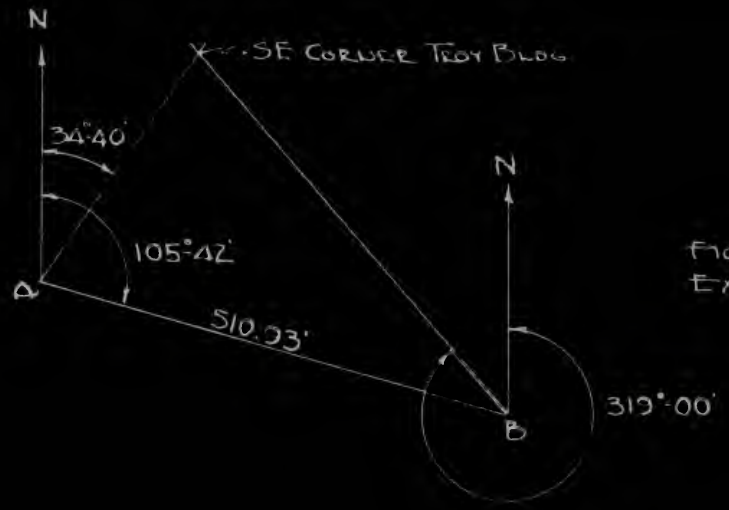
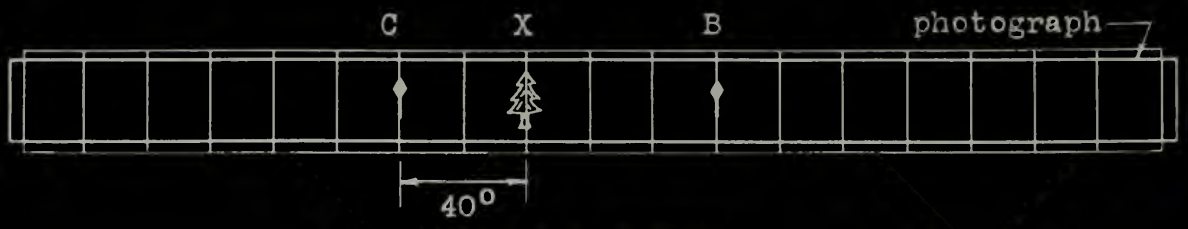
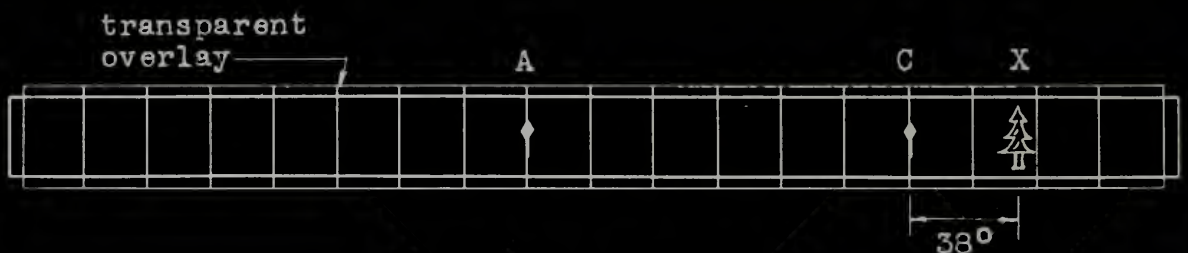


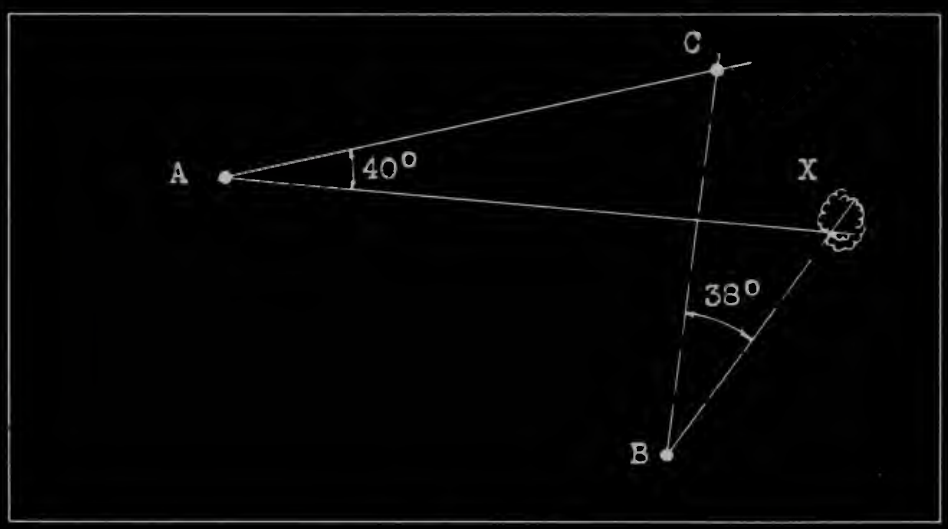
FIG. VII
EXAMPLE OF PLOTTING



Station A Occupied



Station B Occupied



Map Sheet

Fig. VII-2. Planimetric Plotting Procedure.

Showing method of placing overlay grids and transfer of object from photograph to map s heet.

other objects. This procedure eliminates the necessity of numbering or otherwise identifying, for the sake of plotting, any except control points at any time during the course of field or office work. By using a universal drafting machine for plotting bearings, the work may be made to proceed quite rapidly.

SUGGESTIONS

SUGGESTIONS

A. Camera

So far as the authors have been able to learn from their investigations, the camera performs the functions it was designed for fairly satisfactorily, but it is far from ideal. The following suggestions may be helpful to anyone wishing to proceed further with this work.

1. The lens and shutter assembly might well be fixed more rigidly with respect to the film magazine, particularly if the camera is to be used for elevation determinations.

2. Manufacturers will, if given sufficient time, supply roll film of any width, weight, emulsion type, and perforation spacing within reason. The film used was satisfactory as to weight and emulsion type, but was about 12 1/2" wide. The 6 1/4" width to which it was cut is considered a reasonable dimension, at least for use with a 170 mm. focal length lens system. However, cutting it thus left perforations on one edge only. For best results, the film should have perforations on both edges and the camera's film drum should have sprockets to engage both sets of perforations.

3. Some provision should be made to eliminate backlash in the driving gears. A reduction in motor supply voltage might be the answer. Surprising as it may seem, the use of a 1/100 horsepower motor constituted over-motoring, due to the very considerable gear reduction. The motor was

apparently so lightly loaded that its speed was limited mainly by its own friction and back emf, and the vertical light streaks on the prints may have been due to the fact that motor speed tended to hunt. A friction drag on camera motion might be another solution to the problem.

4. If elevation plotting is contemplated, an elevation grid inscribed in thin celluloid and covering the slit in front of the film drum would be an aid to accuracy in elevation determinations, since the film may ride up and down a small distance on the drum. It is recommended that such a grid be calibrated in tangents of vertical angles, both to facilitate interpolation and to minimize calculations.

5. If a completely new camera design were contemplated, the substitution of magnesium for aluminum and the substitution of castings, finish machined as required, for the plate-and-angle type of construction, would be worth serious consideration. A considerable reduction in weight and improvement in rigidity, and possibly better mechanical balance and outward appearance might result.

B. Field

Although the experience in the field with the equipment previously mentioned was far from extensive, the authors believe that the field practice as set forth in Section V-B is fairly adequate for the purpose intended. However, there are certain suggestions that might be advantageously noted at this time.

With regard to the targets used, range poles with cardboard squares fastened near the top, the limit of visibility seems to be between one hundred and one hundred and fifty yards. If the camera is to be used in terrain where longer sights are contemplated, it would seem advisable to use either a larger target on the range pole, some type of flag, or a large clearly defined object, ie. house, corner of building, etc., for one station in the control. Under some circumstances, occupation of the point in question might not be possible but at least distance to it could be measured.

One point that must be emphasized is the necessity for placing the targets so that they will be in the correct light to photograph well. Since the accuracy of the work depends on the ease with which objects may be identified on the photograph, it is essential that they be clear and distinct. It is therefore recommended that whenever possible targets be placed so they will reflect light toward the camera. It was found that targets placed under trees, or in generally shaded areas showed up very poorly, or not at all.

For several reasons it was found best to make photographic runs in the middle of the day whenever possible. If the sun is too low in the sky there will be considerable over exposure present when the camera is facing in the direction of greatest light. During the middle of the day general all around lighting conditions were found to be better thus giving better pictures. For greatest detail, however, it was found that a slight overcast was better than a brilliant sun. This evidently stems from the fact that light intensity is about the same, but due to the overcast, shadows do not predominate.

An exposure meter is a great aid in determining the correct lens opening, and it is suggested that one be used whenever possible. The authors found that using a General Electric film speed of 100 and picking the lens opening corresponding to a shutter speed of one hundredth of a second gave good results with Aero-type film that was available.

C. Darkroom

Although no serious trouble was experienced in the darkroom, a few things were noticed that might be classed as outside the usual run of darkroom procedure.

Since the negative from the camera is longer than the usual negative used to make contact prints, some difficulty was encountered in providing a method which would insure complete contact between the film, paper, and glass plate. To expedite printing, a large bath towel was placed on the table and the paper, film, and glass put on top of the towel. This provided sufficient fill for the unevenness of the table top to eliminate the poor contact. If a great number of prints were to be made, it is thought that a long, smooth board, finished to provide a true surface and covered with felt would provide a better answer to the problem.

In this case the problem of illumination for the contact prints was met by using the lighting fixture in the darkroom. The light was satisfactory for rough work, but in cases where the density of the negative varied considerably light of this kind proved inadequate. The answer to the problem undoubtedly lies in providing a type of illumination which can be varied along the length of the negative to meet this changing density. One thought along this line was to equip a long member with three or four light sockets with individual switches. This would allow the light to be very closely controlled at the will of the operator, and operated in conjunction with a standard electrical photographic enlarging timer would give excellently controlled prints.

RESULTS AND CONCLUSIONS

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It is felt by the authors that the design and development of a camera capable of taking a complete and continuous picture for three hundred and sixty degrees around a point, and the application of the resultant picture to terrestrial photogrammetry represents a decided step forward in this field.

As pointed out in the introduction, the long and laborious process of plotting from several photographs combined with the orienting procedure necessary with individual prints has been replaced with the continuous picture and transparent overlay.

The fact that a small area was photographed and mapped in a fraction of the time that ordinary surveying methods would take encourages the thought that this method may possibly have greater uses. With one good day in the field, the photographer can bring in enough data to keep the office busy for a period of several days.

Although the initial outlay for apparatus such as this, and the necessary facilities for developing and printing will run rather high, it is thought that for some concern specializing in this type of work considerable saving might be realized. Not only will the actual time spent in mapping be less, but the attendent cost of field parties will be materially reduced.

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RENSSELAER POLYTECHNIC INSTITUTE
DEPT OF CIVIL ENGINEERING

MAP OF PART OF R.P.I. CAMPUS

BASED ON PHOTOGRAMMETRIC SURVEY USING 360° PANORAMIC CAMERA

SCALE 1" = 50'

DRAWN BY R.B. JARVIS 23 JULY 68

SAGE ANNEX

TROY BUILDING

RICKETTS BUILDING

GREENE BUILDING

FLETCHER

105°42'
510.93'

F.3

F.5

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